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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Our research efforts were focussed on the study of spin polarized atoms, nuclei and electrons during the period covered by this report. Although this work is 6.1 basic research, it has applications to a number of important Air Force problems. For example, the atomic clocks used on the GPS satellite system operate with optically pumped Rb absorption cells, very similar to the ones being investigated in our laboratory. A number of the scientists and engineers working on atomic clocks used by Air Force satellite systems were trained with the support of this grant. We have participated in recent Air Force advisory panels to review concepts for high-energy-density fuels based on spin polarized atoms and molecules. The insights we have gained from research sponsored by this grant have been very useful to us in evaluating these ideas. Our recent work has focussed on two main areas, the investigation of quadrupolar interactions between spin polarized noble gas nuclei and surfaces and the quantitative investigation of how magnetic field inhomogeneities cause spin relaxation.

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FINAL TECHNICAL REPORT

For the Research Period
Oct. 1, 1986 through April 30, 1988
for work performed under

Grant AFOSR-85-0171

THE PHYSICS OF SPIN POLARIZED ATOMIC VAPORS.

Submitted May 26, 1988

1. Introduction

Our research efforts were focussed on the study of spin polarized atoms, nuclei and electrons during the period covered by this report. Although this work is 6.1 basic research, it has applications to a number of important Air Force problems. For example, the atomic clocks used on the GPS satellite system operate with optically pumped Rb absorption cells, very similar to the ones being investigated in our laboratory. A number of the scientists and engineers working on atomic clocks used by Air Force satellite systems were trained with the support of this grant. We have participated in recent Air Force advisory panels to review concepts for high-energy-density fuels based on spin polarized atoms and molecules. The insights we have gained from research sponsored by this grant have been very useful to us in evaluating these ideas. Our recent work has focussed on two main areas, the investigation of quadrupolar interactions between spin polarized noble gas nuclei and surfaces and the quantitative investigation of how magnetic field inhomogeneities cause spin relaxation.

2. Quadrupolar Surface Interactions of Noble Gas Nuclei

One of our major research efforts of the past six months has been work on coherent quadrupole interactions of noble gas nuclei with the inner surface of the glass cell which contains the noble gas. Free alkali metal must also be present in the glass cell to make it possible to artificially spin polarize the noble gas nuclei by optical pumping with a laser. The composition of the glass surface is substantially modified because of the absorption of alkali metal atoms. The walls of a freshly manufactured cell will absorb alkali atoms for several days at a cell temperature of 80 C, and this "curing" process has a dramatic effect on the quadrupolar surface interactions of ^{131}Xe nuclei. The cured walls of the cell seem to be much smoother on an atomic scale than the initial glass walls, as evidenced by the fact that the cured cell has a pronounced, coherent quadrupole interaction. Our measurements show that the coherent quadrupole interaction in a cured cell can be described by a mean twist of the nuclear polarization of the ^{131}Xe atom by $38 \pm 4\mu$rad about the surface normal direction for each bounce against the wall. The root-mean-squared twist per bounce is much larger, $1700 \pm 100\mu$rad, which shows that the wall is extremely rough on a microscopic scale.

Quantitative studies in our laboratory show that several monolayers of alkali atoms must be absorbed by the glass wall before the curing process approaches completion. It is not possible to maintain the normal equilibrium vapor pressure of the alkali metal atoms

in the cell until the curing is complete, and we have used this fact to measure the current of atoms to the cell walls. We monitor the diffusion current of atoms to the cell walls by observing the scattering of a resonant laser beam from the alkali metal atoms.

We have published two papers concerning the coherent quadrupolar wall interactions. One paper describes the results of our experimental investigations of the phenomenon, and a second paper describes a new, perturbative theory of the wall interactions.

3. Experimental and Theoretical Studies of Spin Relaxation Due to Magnetic Field Inhomogeneities

One of the major sources of relaxation for the spin polarized nuclei of noble gases is the inhomogeneity of the magnetic field in which the gases are situated. We have completed a systmatic study of how field inhomogeneities cause spin relaxation in gases. We have used the perturbative theoretical methods which we developed to understand the quadrupolar surface interactions to work out a quantitative theory for spin relaxation due to static and oscillating magnetic field inhomogeneities. We find that the longitudinal spin relaxation rates in the rotating frame are greatly accelerated at magnetic resonance. Experimentally measured rates are in very good agreement with theory. Our work shows that a quantitative study of the spin relaxation of gases in inhomogeneous magnetic fields is an excellent way to measure diffusion constants. The final phase of this work is being completed as this report is written, but the basic theoretical paper has already been published, and is listed below as ref. 10. We have just completed a manuscript, "Spin Relaxation in Gases Due to Inhomogeneous Static and Oscillating Fields," by G. Cates, D. J. White, Ting-Ray Chien, S.R. Schaefer, and W. Happer. This paper, which is available in preprint form in advance of publication, contains details of our experimental studies and a generalization of the work of ref. 10 to the case of oscillating magnetic fields and magnetic resonance conditions.

4. Publications

A more detailed description of the work supported by Grant AFOSR-85-0171 during the grant period can be found in the following publications:

1. W. Happer, X. Zeng, Z. Wu, T. Call, E. Miron and D. Schreiber, "Experimental Determination of the Rate Constants for Spin Exchange between Optically Pumped K, Rb, and Cs Atoms and ^{129}Xe Nuclei in Alkali-Metal-Noble-Gas van der Waals Molecules," Phys. Rev. **31**, 260 (1985).

2. F. Calaprice, W. Happer, D. Schreiber, M.M. Lowry, E. Miron and X. Zeng , "Nuclear Alignment and Magnetic Moments of $^{133}Xe^m$ and $^{131}Xe^m$ by Spin Exchange with Optically Pumped ^{87}Rb," Phys. Rev. Letters **54**,174 (1985).

3. Z. Wu, T. G. Walker and W. Happer, "Spin Rotation Interaction of Noble Gas Alkali Metal Atom Pairs," Phys. Rev. Letters **54**,1921(1985).

4. W. Happer, "Comment on 'Binary Formation of NaNe Quasibound Molecules Observed in Spin Relaxation of Na'," Phys. Rev. **A31**, 4020 (1985).

5. J. Hsu, Z. Wu and W. Happer, " ^{129}Xe Nuclear Spin Relaxation in N_2 and He Buffer Gas," Physics Letters **112A**, 141 (1985).

6. F. C. Mackintosh, Z. Wu and W. Happer, "A Measurement of the Spin-Rotation Coupling in NaXe Molecules," Physics Letters **112A**, 435 (1985).

7. Z. Wu, M. Kitano, W. Happer, M. Hou and J. Daniels, "Optical Determination of Alkali Metal Vapor Number Density Using Faraday Rotation," Applied Optics, **25**,4483 (1986).

8. Z. Wu, W. Happer, and J. Daniels, "Coherent Nuclear Spin Interactions of Adsorbed ^{131}Xe Gas with Surfaces," Phys. Rev. Letters **59**, 480 (1987).

9. Z. Wu, S. Schaefer, G. D. Cates and W. Happer, "Coherent Interactions of the Polarized Nuclear Spins of Gaseous Atoms with the Container Walls," Phys. Rev. A **37**, 1161 (1988).

10. G. Cates, S. Schaefer and W. Happer, "Relaxation of Spins Due to Field Inhomogeneities in Gaseous Samples at Low Magnetic Fields and at Low Pressures," Phys. Rev. A **37**, 2877 (1988).

5. Personnel

The following personnel received full or partial support from the grant during the period covered by this report:

Dr. William Happer, Principal Investigator

Dr. Zhen Wu, Research Associate (now at Columbia University)

Dr. Gordon Cates, Research Associate

Dr. Keith Bonin, Assistant Professor

Mr. Steven Schaefer, Graduate Student and PhD Candidate

Mr. Thad Walker, Graduate Student and PhD Candidate

Mr. Steven Redsun, Graduate Student and PhD Candidate

Mr. Ting-Ray Chien, Graduate Student and PhD Candidate

Miss Contee Bowman, Undergraduate Senior Thesis Student

Mr. Sander Kim, Undergraduate Senior Thesis Student

Mr. Dan White, Undergraduate Senior Thesis Student

Mr. Nick Ulman, Undergraduate Senior Thesis Student

Miss Contee Bowman was awarded a Hertz Fellowship for Graduate School, partially in recognition for her research work with our group during her junior and senior academic years at Princeton.